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THERMAL CRACK CONTROL OF MASS CONCRETE

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MICROMEDIA

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THERMAL CRACK CONTROL OF MASS CONCRETE

by

V. Sivasundaram*

ABSTRACT

This report presents the results of an investigation carried out at CANMET on behalf of the Department of Public Works on the mixture proportioning and thermal crack control of a mass concrete element. The above element of dimensions 8.8 x 7.3 x 2.7 m is to be cast as a monolithic mass at the Communications Research Center. A number of lean concrete mixtures incorporating high volumes of low-calcium fly ash, superplasticizer and air entraining admixture were made and tested at CANMET laboratories in order to obtain a workable concrete with the required mechanical properties at 91 days. Following the above investigations, a concrete block of dimensions 1.5 x 1.5 x 1.5 m was cast at the CANMET laboratory under controlled ambient and placing temperatures in order to reduce the temperature rise due to the hydration of cementitious materials.

The measured temperature rise in the block was found to be lower than the computed temperature rise, and no thermal cracks developed in the concrete block. Compressive strength and modulus of elasticity measurements obtained from cast cylinders at 3, 7, 28, 91 days and 91 day cores from the block gave excellent results. Following the satisfactory performance of the above block cast at CANMET, the mixture proportions selected as optimum for the 8.8 x 7.3 x 2.7-m concrete element are presented. Further, the computed maximum temperature in this element for selected placing and ambient temperatures is given, and under these conditions, the thermal strain to be developed in the concrete is shown to be less than its thermal strain capacity.

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CONTRÔLE DE LA FISSURATION THERMIQUE D'UN BLOC EN BÉTON MASSIF

par

V. Sivasundaram*

RÉSUMÉ

Le présent rapport présente les résultats d'une étude effectuée par le CANMET pour le compte du ministère des Travaux publics ayant pour objet le dosage de la richesse du mélange et le contrôle de la fissuration thermique d'un élément en béton massif. Les dimensions dudit élément sont 8,8 x 7,3 x 2,7 m, et il doit être coulé sous forme de masse monolithique au Centre de recherche sur les communications. Un certain nombre de mélanges de béton pauvre comprenant des volumes élevés de cendres volantes à faible teneur en calcium, des superplastifiants et l'addition d'entraîneurs d'air ont été réalisés et essayés dans les laboratoires du CANMET dans le but d'obtenir un béton usinable possédant les propriétés mécaniques requises au bout de 91 jours. Suite aux études susmentionnées, un bloc en béton aux dimensions de 1,5 x 1,5 x 1,5 m a été coulé au laboratoire du CANMET sous des températures ambiantes et de prise contrôlées, afin de réduire l'élévation de température due à l'hydratation des matériaux de cémentation.

On a trouvé que la hausse de température mesurée à l'intérieur du bloc était moins élevée que la hausse de température calculée sur ordinateur et de plus, aucune fissure ne s'est développée à l'intérieur du bloc. Les mesures de la résistance à la pression et du module d'élasticité obtenues à des intervalles de 3, 7, 28 et 91 jours à partir de cylindres coulés et de carottes agées de 91 jours provenant du bloc en béton ont donné d'excellents résultats. Par conséquent, suite à la performance satisfaisante du bloc

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coulé au laboratoire du CANMET, on présente dans ce rapport les proportions du mélange choisies comme étant les meilleures pour obtenir l'élément de béton de 8,8 x 7,3 x 2,7 m. De plus, les données sur la température maximale calculée sur ordinateur pour cet élément en béton au niveau des températures de prise et ambiantes choisies sont aussi présentées. Enfin, la déformation thermique devant se produire dans le béton dans ces mêmes conditions est indiquée comme étant moindre que sa capacité de déformation thermique.

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INTRODUCTION

Differential temperature changes in mass concrete structures tend to cause tensile stresses beyond the strength of the concrete and, if uncontrolled, result in failure producing cracks. These differential temperature changes result from two principal causes: (i) the generation of heat within the mass from the hydration of cement and the dissipation of this heat to the air at the boundary surfaces, (ii) the heating and cooling of the surface of the concrete from periodic cycles of ambient temperature (1). The most difficult source of cracking to control is at formed surfaces, where, in addition to cooling from the maximum temperature caused by heat generation of the cement, weather fluctuations are added. Again, the surface often undergoes drying shrinkage which causes tension at the surface and helps to start the cracks (2). At the request of the Department of Public Works, the present investigation was initiated in order to provide a particular mass concrete element of adequate strength and modulus without the potential for thermal cracking. The above concrete pad of dimensions 8.8 x 7.3 x 2.7 m is to be cast as a monolithic mass in permanent steel forms indoors at the Communications Research Center, with a target 90-day compressive strength equal to or above 35 MPa.

SCOPE OF INVESTIGATION

The scope of this investigation is to (i) proportion a mass concrete mixture without the potential for thermal cracking while having adequate strength and modulus properties, (ii) cast sample specimens to verify the performance of the mixture, (iii) provide specifications for the mix and the method of placing and curing of the mass concrete pad.

TEMPERATURE RISE IN MASS CONCRETE

Reduction in temperature is usually associated with cracking tendency of concrete. Cracking in mass concrete is generally caused by tensile failure resulting from contraction of concrete under conditions of

restraint, as it cools from its maximum temperature to a stable condition. Therefore measures which prevent a large reduction in temperature are usually effective in preventing cracks. High temperatures are caused by the heat evolved chemically in the cement during its setting and hardening process. The factors which affect the maximum value reached are: dimensions of the structure, heat generation of cement, richness of mix, initial concrete temperature, type of forms, ambient temperature, rate of construction, and thermal properties of concrete. In most cases, the aim is to avoid high temperatures and large temperature gradients.

In mass concrete construction a number of special precautions may be taken to prevent steep temperature gradients. The usual methods include: use of leaner mixes, use of low heat or modified portland cement, partial substitution of pozzolans for cement, a restriction on the height of lifts, a rigid placing schedule, precooling of mixing water and aggregates, and accelerated cooling of the concrete after placing by internal circulating pipes (3).

The temperature distribution in the concrete at any time after placing may be estimated from the knowledge of the heat generation characteristics of the cement, thermal properties of the concrete, initial and boundary conditions, and details of the procedures of construction. The determination of temperature gradients in mass concrete by Schmidt's method (3) is given in Appendix A.

MATERIALS

The concrete mixtures were made using the following materials.

Cement

Portland cement (ASTM Type II) was used because of its moderate heat generating characteristics. ASTM Type IV low heat cement, which would have been more appropriate for the investigation, was not readily available. Typical physical properties and chemical analysis of the Type II cement are given in Table 1.

Fly Ash

Low-calcium fly ash from a source in Eastern Canada was used. Typical physical properties and chemical analysis of the fly ash are given in Table 1.

Aggregates

The coarse fraction consisted of 19-mm (3/4-in.) crushed limestone and the fine fraction was natural sand. The grading and physical properties of both fine and coarse aggregates are given in Tables 2 and 3.

Superplasticizer (High-Range Water Reducer)

A sulfonated naphthalene formaldehyde condensate superplasticizer of Japanese origin was used. It is available as a dark brown 42% solids aqueous solution having a density of 1200 kg/m^3. The chloride content is negligible.

Air-Entraining Agent

A sulfonated hydrocarbon type air-entraining agent was used.

CONCRETE MIXTURES

The 0.07 m^3 (2.4 ft^3) mixtures were prepared in the CANMET laboratory during October 85 to January 86 using a counter current mixer with the exception of a 4.0 m^3 (5.2 yd^3) batch, for which a ready mixed truck was used. The 4.0 m^3 mix was made mainly for temperature monitoring of the concrete mass. In this case, the coarse and fine aggregates were loaded in the truck at a ready mixed plant and the rest of the ingredients were loaded at CANMET laboratory. For the other mixtures, the graded coarse and fine aggregates were weighed in room-dry condition. The coarse aggregate was then immersed in water for 24 h; the excess water was decanted and the amount of water retained by the aggregate was determined by weight difference. A predetermined amount of water was added to the fine aggregate, which was then allowed to stand for 24 h.

The mixture proportioning details are given in Table 4. The underlying principle of the mixture proportioning was to produce a lean concrete with reduced heat of hydration, so as to provide a minimal temperature rise above ambient conditions while having adequate strength and modulus of elasticity required for the specific need. This objective was achieved by (i) maintaining the cement content at a low-level of 150 kg/m^3 (255 lb/yd^3), (ii) maintaining the water-to-(cement+fly ash) ratio at about 0.30 and keeping the unit water content between 95 and 113 kg/m^3 (160 and 190 lb/yd^3), (iii) controlling the placing temperature of the mass concrete at 12°C (54°F). In order to obtain this predetermined placing temperature, the cement and fly ash were precooled overnight to a temperature of -2°C (28°F). The mixing water was kept at 1°C (34°F), and the aggregates were kept at -4°C (25°F). The mixing was done under atmospheric conditions, at a temperature of -7°C (19°F). In all the mixes, the required workability was achieved by the use of a superplasticizer. The properties of fresh-mixed concrete i.e. temperature, slump, unit weight, and air content are given in Table 4.

CASTING AND CURING OF TEST SPECIMENS

Ten 152 x 305-mm (6 x 12-in.) cylinders were cast from each mixture except for the special mixture No. 5 from which a concrete block measuring 1.5 x 1.5 x 1.5 m (5 x 5 x 5 ft) was cast in a wooden form in addition, and mixture No. 1 from which only six cylinders were cast. All cylinders were cast in two layers, each layer being compacted using an internal vibrator. The large block was cast in one continuous operation using concrete from a ready-mixed truck and was compacted using large internal vibrators. As given in Appendix B, the placing temperature of mixture No. 5 was controlled at 12°C (54°F), and the temperature of the casting room was maintained at 24°C (75°F). Immediately after casting, thermocouples were installed at various locations inside the mass concrete in order to monitor the temperature rise.

After casting, the moulded specimens and the large block were covered with water saturated burlap and left in the casting room for 24 h. The cylinders were then demoulded, and densities were determined. Following

this, the cylinders were transferred to the moist-curing room until required for testing. The large block, weighing about 8.7 metric tons (19,250 lbs.), was stripped of the wooden forms, covered with burlaps, and was cured with water at room temperature for two weeks continuously by means of a sprinkler system. The temperature monitoring also continued till the temperature of the concrete mass has stabilized. About two weeks later, once the concrete reached its final stable temperature, curing continued with tap water for a period of over 91 days. At 91 days, 102 x 203-mm (4 x 8-in.) and 152 x 305-mm (6 x 12-in.) cores were taken from the block at mid-height for the determination of compressive strength and modulus of elasticity.

TESTING OF SPECIMENS

Two cylinders from each mixture were tested in compression at 3, 7, 28 and 91 days. The exceptions were mix No. 1, from which cylinders were tested at 3, 35 and 91 days, and mix No. 5 from which cylinders were also tested at one day. All specimens for compression testing were capped and tested in accordance with standard ASTM methods. At 91 days, selected cores and cylinders were tested for modulus of elasticity. Further, pulse velocity measurements were taken along 12-in grids on both pairs of block faces at 14, 28 and 91 days.

RESULTS AND DISCUSSION

Temperature Rise

An approximate step-by-step method developed by Schmidt for the computation of temperature distribution in mass concrete is detailed in Appendix A. The temperature distribution in the 1.5 x 1.5 x 1.5-m concrete block for a period of up to 3 days after casting was calculated using Schmidt's method for selected ambient and placing temperatures of 24°C (75°F) and 12°C (54°F) respectively. The computations are given in Appendix B. Tables B1, B2 and B3 give the adiabatic temperature rise in the block, temperature distribution in the block, and the computed and measured

temperatures at mid-depth of the block respectively. The maximum temperature reached in the block and the thermal strain created due to the cooling of the block from the maximum temperature to the final stable temperature, i.e. the ambient temperature, were calculated as 33.2°C (91.7°F) and 33.4 x 10^{-6} respectively. As given in Appendix B, the estimated thermal strain capacity of the above concrete for a sudden drop in temperature is about 62 x 10^{-6}, which is well above the computed thermal strain. Thus, for the selected mixture proportions, placing temperature, and ambient temperature, the analysis ensured a 1.5 x 1.5 x 1.5-m concrete block without the potential for thermal cracking.

The peak temperature measured at mid-depth in the 1.5 x 1.5 x 1.5-m cast block is 31.3°C (88.3°F). Figure B2 shows a comparison of measured and computed temperature distributions at the mid-depth of the block for a period up to 3 days after casting. In this figure, the actual temperature distribution stays below the theoretical temperature distribution. No thermal cracking was observed in the cast block. The pulse velocity measurements on the block gave consistent results and thus confirmed the absence of internal cracks. Also, the pulse velocity measurements compared well with the compressive strength results of cast cylinders.

The computations of the temperature distribution for the 8.8 x 7.3 x 2.7-m (29 x 24 x 9-ft) concrete block, to be cast at the Communications Research Center, are given in Appendix C. Of the five concrete mixtures proportioned and tested, the most appropriate one selected for this block is given in Table 6. The ambient and placing temperatures for this concrete are selected as 24°C (75°F) and 7°C (45°F) respectively. Tables C1 and C2 give the adiabatic temperature rise in the block and the temperature distribution in the block respectively. According to Schmidt's method, the peak temperature to be reached in this concrete is calculated as 33.6°C (92.4°F). And the thermal strain in the concrete due to the cooling of the block from the above peak temperature to the ambient temperature of 24°C (75°F) is calculated to be 34.8 x 10^{-6} as given in Appendix C. This calculated value is less than the thermal strain capacity of 62 x 10^{-6} and thus ensures that this concrete would be free of thermal cracks.

Compressive Strength

The strength test data given in Table 5 demonstrate that the incorporation of large volumes of low-calcium fly ash in suitably proportioned lean concrete mixtures yield sufficiently high strengths at both early- and late-ages. The 91-day strengths obtained in this investigation were of the order of 40 MPa (5800 psi) in case of concrete with w/(c+f) of 0.33, and 53 MPa (7700 psi) in case of concrete with w/(c+f) of 0.28. The above strengths of cast cylinders were confirmed by tests on cores drilled from the 1.5 x 1.5 x 1.5-m block. The strength values obtained are well above the 35 MPa strength requirement at 91-days for the 8.8 x 7.3 x 2.7-m block.

Young's Modulus of Elasticity

The modulus of elasticity results of both the cast cylinders are drilled cores ranged from 37 to 43 GPa (5.4×10^6 to 6.2×10^6 psi). These results are given in Table 5. The high modulus values obtained are considered to be more than adequate for the purpose to which the 8.8 x 7.3 x 2.7-m block will be used.

CONCLUSIONS AND RECOMMENDATIONS

The investigations carried out at CANMET with regard to the mass concrete block yielded satisfactory results in terms of mixture proportions, strength and elasticity properties, and temperature control in order to avoid thermal cracking. The concrete mixtures obtained from the mixture proportions were flowable and had adequate fresh properties. The cast specimens and the 1.5 x 1.5 x 1.5-m concrete block cast at CANMET provided excellent results in terms of strength and modulus properties, and proved that thermal cracking could be avoided by strictly following the given criteria for mixture proportioning, placing temperature, and ambient temperature.

The recommended mixture proportions for the 8.8 x 7.3 x 2.7-m concrete block are given in Table 6 together with the suggested ambient and placing temperatures. It is emphasized that continuous curing with water maintained at ambient temperature should follow for about 3 weeks after casting, and

that curing be continued with ordinary tap water for 91 days after casting. Further, it is suggested that a consultant with extensive experience in mass concrete construction be present during casting of the 8.8 x 7.3 x 2.7-m block.

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Table 1 - Physical Properties and Chemical Analyses of Cement, and Fly Ash

	Portland Cement* (ASTM Type II)	Fly Ash**
Physical Tests		
Fineness - passing 75 μm %	--	--
- passing 45 μm %	90.4	82.7
- Blaine, m^2/kg	368	289
Setting time, min.		--
- Initial	160	
- Final	290	
Autoclave expansion %	+0.082	--
Compressive strength of 51-mm Cubes, MPa: 3-day	21.2	--
7-day	28.2	--
28-day	36.7	--
Chemical Analysis		
Insoluble residue	--	--
Silicon dioxide (SiO_2)	22.52	47.1
Aluminum oxide (Al_2O_3)	3.90	23.0
Ferric oxide (Fe_2O_3)	2.99	20.4
Calcium oxide (CaO), total	63.15	1.21
Magnesium oxide (MgO)	2.67	1.17
Sulphur trioxide (SO_3)	2.80	0.67
Sodium oxide (Na_2O)	0.31	0.54
Potassium oxide (K_2O)	0.41	3.16
Loss on ignition	0.97	2.88
Boque Potential Compounds		
C_3S	47.40%	
C_2S	28.89%	
C_3A	5.28%	
C_4AF	9.09%	

*Manufacturer's data
**CANMET data

Table 2 - Grading of Aggregates

Coarse aggregate		Fine aggregate	
Sieve size	Cumulative percentage retained	Sieve size	Cumulative percentage retained
19.0 mm	0.0	4.75 mm (No. 4)	0.0
12.7 mm	33.4	2.36 mm (No. 8)	10.0
9.5 mm	66.6	1.18 mm (No. 16)	32.5
4.75 mm	100.0	600 µm (No. 30)	57.5
		300 µm (No. 50)	80.0
		150 µm (No. 100)	94.0
		pan	100.0

Table 3 - Physical Properties of Aggregates

	Coarse Aggregate*	Fine Aggregate**
Specific Gravity	2.69	2.70
Absorption, %	0.82	1.1

* Crushed limestone
**Natural sand

Table 4 - Mix Proportions and Properties of Fresh Concrete

Mix No.	Mix Proportions								Properties of Fresh Concrete					
	W/C	W/(C+F)	F/(C+F)	A/C	Cement	Fly Ash	Admixtures		Temperature		Slump		Unit Weight	Air Content %
							SP*	AEA**						
					kg/m³ (lb/yd³)	kg/m³ (lb/yd³)	kg/m³ (lb/yd³)	mL/m³ (mL/yd³)	°C	°F	mm	in.	kg/m³ (lb/ft³)	
1	0.75	0.33	0.56	12.79	151 (255)	193 (325)	2.97 (5.0)	680 (520)	22	71	40	1.5	2410 (150.4)	3.8
2	0.74	0.33	0.56	12.75	150 (253)	191 (322)	2.61 (4.4)	872 (667)	23.5	74	110	4.25	2385 (148.8)	5.2
3	0.74	0.33	0.56	12.76	151 (254)	192 (323)	2.97 (5.0)	1164 (890)	20	68	65	2.5	2400 (149.6)	5.4
4	0.74	0.33	0.56	12.75	150 (253)	190 (321)	2.97 (5.0)	1164 (890)	20	68	75	3.0	2385 (148.8)	5.2
5	0.65	0.28	0.56	12.49	147 (248)	187 (316)	7.12 (12.0)	660 (505)	12	53	200	8.0	-----	2.8

*Superplasticizer
**Air Entraining Agent

Table 5 - Summary of Compressive Strength and Modulus of Elasticity Results

Mix No.	Density at one day	Compressive Strength						91-day Modulus of Elasticity		
		152 x 305-mm (6 x 12-in.) Test Cylinders at Various Ages*				Drilled Cores 91-day		Test Cylinders 152 x 305 mm* (6 x 12 in.)	Drilled Cores	
		3-day	7-day	28-day	91-day	152 x 305 mm** (6 x 12 in.)	102 x 203 mm*** (4 x 8 in.)		152 x 305 mm** (6 x 12 in.)	102 x 203 mm*** (4 x 8 in.)
	kg/m³ (lb/ft³)	MPa (psi)	MPa (psi)	MPA (psi)	MPa (psi)	MPa (psi)	MPa (psi)	GPa (psi x 10^6)	GPa (psi x 10^6)	GPa (psi x 10^6)
1	---	10.5 (1525)	---	34.7† (5030)	43.8 (6350)	---	---	---	---	---
2	2415 (150.7)	12.9 (1875)	17.8 (2585)	27.9 (4050)	40.2 (5830)	---	---	38.7 (5.60)	---	---
3	2400 (149.7)	14.2 (2060)	19.5 (2825)	31.6 (4580)	43.2 (6260)	---	---	39.9 (5.80)	---	---
4	2410 (150.4)	13.3 (1930)	19.4 (2820)	31.5 (4560)	40.9 (5930)	---	---	37.1 (5.35)	---	---
5	2470 (154.0)	9.4†† (1365)	23.9 (3465)	41.6 (6030)	53.1 (7700)	56.8 (8240)	58.0 (8410)	42.3 (6.15)	39.0 (5.65)	42.8 (6.20)

*Each value is average of two tests
**Each value is average of six tests
***Each value is average of three tests
†35-day compressive strength
††1-day compressive strength

Table 6 - Mixture Proportions, Ambient and Placing Temperatures Selected for the 8.8 x 7.3 x 2.7-m Concrete Block

Materials	Weight lb/yd³ (kg/m³)
Coarse Aggregate (dry) (limestone - 3/4" max.)	2136 (1267)
Fine Aggregate (dry) (natural sand)	1126 (668)
Cement (Type II)	255 (151)
Fly Ash (Lingan)	325 (193)
Water	190 (113)
Superplasticizer	5.0 (2.97)
Air Entraining Admixture*	890 mL/yd³ (1164 mL/m³)
Ambient Temperature	24°C (75°F)
Placing Temperature	7°C (45°F)

*The quantity of AEA is given by volume

APPENDIX A

DETERMINATION OF TEMPERATURE DISTRIBUTION IN MASS CONCRETE USING SCHMIDT'S METHOD (3)

The exact prediction of temperature distribution in mass concrete is difficult, due to the complexity of the conditions involved, namely; 1) heat generation of cement varies with time in no simple mathematical manner, (2) heat generation is somewhat affected by the resulting temperatures which are not known at the outset, (3) variations in surface conditions is seldom known accurately, 4) thermal characteristics of concrete vary with age and temperature (3).

Although exact prediction of temperature is practically impossible, prediction that is sufficiently accurate for engineering purposes is feasible. An approximate step-by-step method developed by Schmidt is described below. (Imperial units are used throughout this dicussion).

Only linear heat flow is considered here. And it is assumed that the boundaries parallel to the direction of heat flow are either insulated or too remote from the region under consideration to cause any significant distortion in flow lines.

An elemental prism of material having a uniform cross-sectional area of A sq. ft. is considered, with its axis parallel to the direction of heat flow. It is considered to be divided into a number of equal elements of length Δx. Figure A1 shows three adjacent elements p, q and r with temperatures of θp, θq, and θr respectively at their centers. The space interval Δx is chosen small enough to permit the assumption that the temperature at the center of an element is the mean temperature of the element, and the temperature gradients between the centers are assumed to be linear. The rate of heat flow is assumed to remain constant during an interval of time Δt.

Since the quantity of heat conducted across the surface of a body is equal to the product of (1) the average temperature gradient during the time interval, (2) the coefficient of thermal conductivity, (3) the sectional area, and (4) the elapsed time:

The flow of heat from r to q in time Δt,

$$Q_1 = \frac{kA\ (\theta r - \theta q)\ \Delta t}{\Delta x}$$

The flow of heat from q to p in time Δt,

$$Q_2 = \frac{kA\ (\theta q - \theta p)\ \Delta t}{\Delta x}$$

where θ denotes temperature in °F

k denotes thermal conductivity in B.Th.U/ft/day/°F

The heat absorbed at q,

$$\begin{aligned} Q &= Q_1 \mp Q_2 \\ &= \frac{kA}{\Delta x}(\theta r - \theta q)\ \Delta t - \frac{kA}{\Delta x}(\theta q \mp \theta p)\ \Delta t \\ &= \frac{kA}{\Delta x}\ \Delta t\ (\theta p + \theta r - 2\theta q) \end{aligned}$$

Since the heat absorbed is equal to the product of, (1) the volume, (2) the specific heat per unit weight, (3) the density, (4) temperature rise; the temperature rise at q,

$$\begin{aligned} \Delta\theta q &= \frac{kA\ \Delta t}{\Delta x}(\theta p + \theta r - 2\theta q)/c\rho A\Delta x \\ &= \frac{k\ \Delta t}{c\rho(\Delta x)^2}(\theta p + \theta r - 2\theta q) \\ &= \frac{h^2\Delta t}{(\Delta x)^2}(\theta p + \theta r - 2\theta q) \end{aligned}$$

where c denotes specific heat

ρ denotes density in lb/cu. ft.

and $h^2 = \frac{k}{\rho c}$ is the thermal diffusivity in sq. ft./day

The temperature at q at the end of the time interval is then given as

$$\theta q^1 = \theta q + \Delta\theta q$$

$$= \theta q + \frac{h^2 \Delta t}{(\Delta x)^2} (\theta p + \theta r - 2\theta q)$$

If Δt is chosen in relation to Δx so that

$$\frac{h^2 \Delta t}{(\Delta x)^2} = \frac{1}{2}$$

then $$\theta q^1 = \theta q + \frac{1}{2} (\theta p + \theta r - 2\theta q)$$

$$= \frac{1}{2} (\theta p + \theta r)$$

This means that the arithmetic mean of the temperatures at two alternate points at any instant gives the temperature at the intermediate point after an interval of time equal to $\frac{(\Delta x)^2}{2h^2}$

In addition to the change in temperature in an element due to heat flow, there may be a change due to heat generation within the volume. The equivalent temperature rise of heat generation, or "adiabatic temperature rise", termed $\Delta\theta$ is added to θq^1.

The above method was developed for application to a tabular method of solution of temperature distribution. To begin computations, the number of elements are decided such that the boundaries pass through the centers of first and last elements. An equal number of columns is drawn up in the calculation sheet, and the initial temperature of the corresponding element is written in the first line of each column. The second line representing the temperatures after the first interval is obtained by averaging alternate temperatures in the first line. The adiabatic temperature rise during that interval is added to the average temperatures obtained above. This way the computation is continued to the desired number of time intervals.

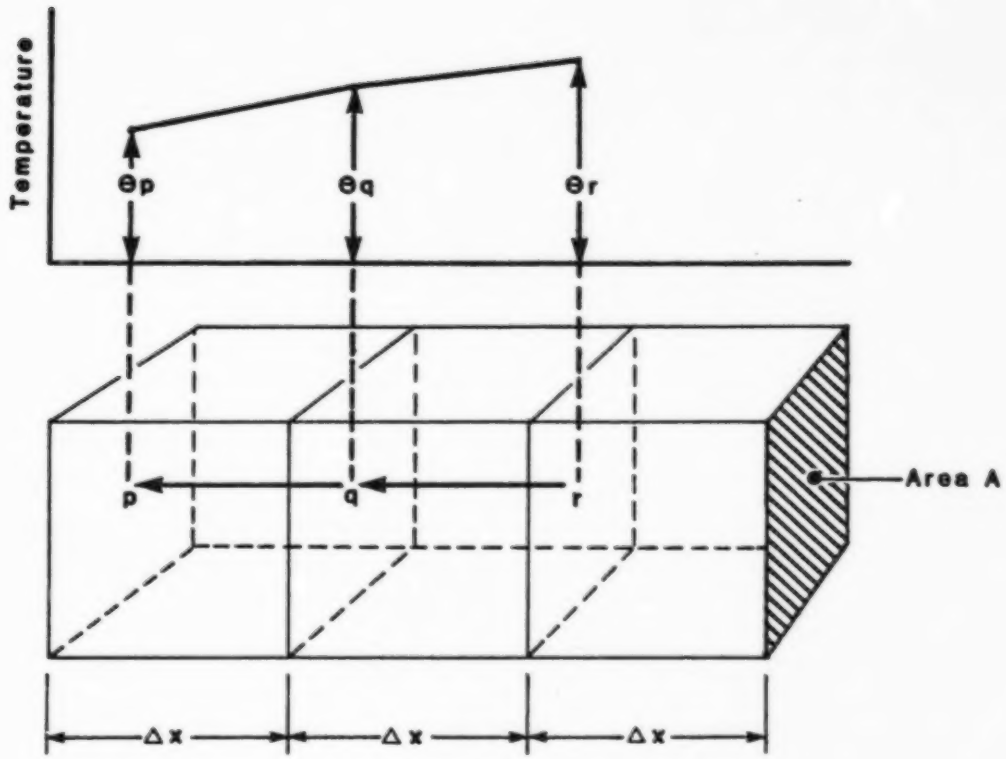

Fig. A1. Heat Flow in Three Adjacent Elements.

APPENDIX B

(A) Numerical Computation of Temperature Distribution in the 1.5 x 1.5 x 1.5-m (5 x 5 x 5-ft) Concrete Block using Schmidt's Method

The mixture proportioning of the above concrete block, i.e. mix no. 5, is given in Table 4. The space and time intervals selected are small because of the finite thickness of 1.5 m (5 ft).

The thermal diffusivity of concrete incorporating limestone aggregate is 1.22 sq. ft/day (5).

Let $\Delta x = 0.5$ ft; then $\Delta t = \frac{(\Delta x)^2}{2h^2} = 0.084$ day = 2 hrs

The temperature distribution is symmetrical about the central plane and hence it is only necessary to calculate the temperatures for one half of the block. The adiabatic temperature rise curves for mass concretes containing 376 lb/cu yd (223 kg/m^3) of various types of cements are shown in Fig. B1 (4). From this figure, the adiabatic temperature rise in the block is estimated by multiplying the values shown on the curve for type II cement by a factor representing the proportion of the cement. The slow hydration of fly ash incorporated in the mix is taken into account by considering that fly ash contributes about 25% as much heat as the cement it replaces.

Therefore, for the cement content of 248 lb/cu yd and fly ash content of 316 lb/cu yd, the equivalent cement content,

$$C_{eq} = 248 + 316/4 = 327 \text{ lb/cu yd}$$

The adiabatic temperature rise for an equivalent cement content of 327 lb/cu yd is shown in column 4 of Table B1. And the successive increments of adiabatic temperature at 2 hr intervals are shown in column 5 of Table B1. The temperature distribution in the block, up to 3 days from placing is computed as shown in Table B2.

(B) The Tensile Strain Caused by Cooling of the 1.5 x 1.5 x 1.5-m Block from the Peak Temperature to the Final Stable Temperature

The principal cause of cracking in mass concrete is the thermal stresses created during cooling of the concrete from the peak temperature. Therefore, to avoid cracking due to thermal stresses, the concrete placing temperature should be such that the potential strain resulting from the temperature decline from the initial peak value to the final stable temperature does not exceed the strain capacity of the concrete.

The following relationship is used to estimate the thermal strain in concrete (5):

$$\Delta t = \frac{100 \times C}{e_t \times R}$$

where Δt = temperature difference from the initial peak to the final stable temperature

C = thermal strain in concrete

e_t = coefficient of thermal expansion per degree of temperature

R = degree of restraint (in per cent)

For the 1.5 x 1.5 x 1.5-m concrete block:
From the computation, $\Delta t = 91.7 - 75 = 16.7°F$
For concrete with limestone aggregates, $e_t = 4.0 \times 10^{-6}/°F$

As there are no restraints in the block other than the internal restraint within the concrete, the value of R is taken as 50%

$$C = \frac{16.7 \times 4.0 \times 10^{-6} \times 50}{100}$$

$$= 33.4 \times 10^{-6}$$

From Ref. 5, at about 7 days after placing, for a sudden drop in temperature in concretes with aggregates of crushed limestone and natural sand and a water-to-cementitious materials ratio of 0.47, the tensile strain capacity is given as 62×10^{-6}.

For a concrete placing temperature of 54°F and ambient temperature of 75°F, the computed tensile strain in the 1.5 x 1.5 x 1.5-m block is 33.4 x 10^{-6}, which is smaller than the tensile strain capacity given above. Therefore, the temperature control measures suggested for the 1.5 x 1.5 x 1.5-m concrete block is satisfactory in providing a crack-free concrete.

Table B1 Adiabatic Temperature Rise in the 1.5 x 1.5 x 1.5-m Concrete Block

Time (hrs.)	Adiabatic temperature rise (°C) for cement content of 376 lb/cu yd	Adiabatic temperature rise (°F) for cement content of 376 lb/cu yd	Adiabatic temperature rise (°F) for C_{eq} = 327 lb/cu yd	Δθ (°F)
0	0	0	0	0
2	0.5	0.9	0.8	0.8
4	1.3	2.3	2.0	1.2
6	2.0	3.6	3.1	1.1
8	2.5	4.5	3.9	0.8
10	3.8	6.8	5.9	2.0
12	6.0	10.8	9.4	3.5
14	7.5	13.5	11.7	2.3
16	11.5	20.7	18.0	6.3
18	14.0	25.2	21.9	3.9
20	15.0	27.0	23.5	1.6
22	16.0	28.8	25.0	1.5
24	17.0	30.6	26.6	1.6
26	17.5	31.5	27.4	0.8
28	18.0	32.4	28.2	0.8
30	18.5	33.3	29.0	0.8
32	19.3	34.7	30.2	1.2
34	20.0	36.0	31.3	1.1
36	20.5	36.9	32.1	0.8
38	21.3	38.3	33.3	1.2
40	22.0	39.6	34.4	1.1
42	22.5	40.5	35.2	0.8
44	23.0	41.4	36.0	0.8
46	23.3	41.9	36.4	0.4
48	23.5	42.3	36.8	0.4
50	23.8	42.8	37.2	0.4
52	24.3	43.7	38.0	0.8
54	24.5	44.1	38.4	0.4
56	24.8	44.6	38.8	0.4
58	25.0	45.0	39.1	0.3
60	25.5	45.9	39.9	0.8
62	25.8	46.4	40.4	0.5
64	26.0	46.8	40.7	0.3
66	26.3	47.3	41.1	0.4
68	26.5	47.7	41.5	0.4
70	26.8	48.2	41.9	0.4
72	27.0	48.6	42.3	0.4

Table B2 - Temperature Distribution in the 1.5 x 1.5 x 1.5-m Concrete Block

Time (hrs.)	Distance from one boundary (ft)					
	0	0.5	1.0	1.5	2.0	2.5
0 (a_1)	75	54	54	54	54	54
(b_1)		0.8	0.8	0.8	0.8	0.8
2 (a_2)	75	65.3	54.8	54.8	54.8	54.8
		1.2	1.2	1.2	1.2	1.2
4	75	66.1	61.3	56.0	56.0	56.0
		1.1	1.1	1.1	1.1	1.1
6	75	69.3	62.2	59.8	57.1	57.1
		0.8	0.8	0.8	0.8	0.8
8	75	69.4	65.4	60.5	59.3	57.9
		2.0	2.0	2.0	2.0	2.0
10	75	72.2	67.0	64.4	61.2	61.3
		3.5	3.5	3.5	3.5	3.5
12	75	74.5	71.8	67.6	66.4	64.7
		2.3	2.3	2.3	2.3	2.3
14	75	75.7	73.4	71.4	68.5	68.7
		6.3	6.3	6.3	6.3	6.3
16	75	80.5	79.9	77.3	76.4	74.8
		3.9	3.9	3.9	3.9	3.9
18	75	81.4	82.8	82.1	80.0	80.3
		1.6	1.6	1.6	1.6	1.6
20	75	80.5	83.4	83.0	82.8	81.6
		1.5	1.5	1.5	1.5	1.5
22	75	80.7	83.3	84.6	83.8	84.3
		1.6	1.6	1.6	1.6	1.6
24	75	80.8	84.3	85.2	86.1	85.4
		0.8	0.8	0.8	0.8	0.8
26	75	80.5	83.8	86.0	86.1	86.9
		0.8	0.8	0.8	0.8	0.8
28	75	80.2	84.1	85.8	87.3	86.9
		0.8	0.8	0.8	0.8	0.8
30	75	80.4	83.8	86.5	87.2	88.1
		1.2	1.2	1.2	1.2	1.2
32	75	80.6	84.7	86.7	88.5	88.4
		1.1	1.1	1.1	1.1	1.1
34	75	81.0	84.8	87.7	88.7	89.6
		0.8	0.8	0.8	0.8	0.8
36	75	80.7	85.2	87.6	89.5	89.5
		1.2	1.2	1.2	1.2	1.2
38	75	81.3	85.4	88.6	89.8	90.7
		1.1	1.1	1.1	1.1	1.1
40	75	81.3	86.1	88.7	90.8	90.9
		0.8	0.8	0.8	0.8	0.8
42	75	81.4	85.8	89.3	90.6	91.6
		0.8	0.8	0.8	0.8	0.8
44	75	81.2	86.2	89.0	91.3	91.4
		0.4	0.4	0.4	0.4	0.4

Table B2 - (Cont'd)

Time (hrs.)	Distance from one boundary (ft)					
	0	0.5	1.0	1.5	2.0	2.5
46	75	81.0	85.5	89.2	90.6	91.7
		0.4	0.4	0.4	0.4	0.4
48	75	80.7	85.5	88.5	90.9	91.0
		0.4	0.4	0.4	0.4	0.4
50	75	80.7	85.0	88.6	90.2	91.3
		0.8	0.8	0.8	0.8	0.8
52	75	80.8	85.5	88.4	90.8	91.0
		0.4	0.4	0.4	0.4	0.4
54	75	80.7	85.0	88.6	90.1	91.2
		0.4	0.4	0.4	0.4	0.4
56	75	80.4	85.1	88.0	90.3	90.5
		0.3	0.3	0.3	0.3	0.3
58	75	80.4	84.5	88.0	89.6	90.6
		0.8	0.8	0.8	0.8	0.8
60	75	80.6	85.0	87.9	90.1	90.4
		0.5	0.5	0.5	0.5	0.5
62	75	80.5	84.8	88.1	89.7	90.6
		0.3	0.3	0.3	0.3	0.3
64	75	80.2	84.6	87.6	89.7	90.0
		0.4	0.4	0.4	0.4	0.4
66	75	80.2	84.3	87.6	89.2	90.1
		0.4	0.4	0.4	0.4	0.4
68	75	80.1	84.3	87.2	89.3	89.6
		0.4	0.4	0.4	0.4	0.4
70	75	80.1	84.1	87.2	88.8	89.7
		0.4	0.4	0.4	0.4	0.4
72	75	80.0	84.1	86.9	88.9	89.2

Row a_1 represents the initial temperature distribution

Row b_1 gives the increment in adiabatic temperature to be added to the average temperature at alternate stations in a_1

Row a_2 is the temperature distribution at the end of the first time interval and at the beginning of the next

Table B3 - Computed and measured temperatures at mid-depth of the 1.5 x 1.5 x 1.5-m concrete block up to 3 days after casting

Time after placing (hrs.)	Computed temperature (°F)	Measured temperature (°F)
0	54.0	54.0
2	54.8	55.8
4	56.0	56.5
6	57.1	57.4
8	57.9	59.5
10	61.3	62.0
12	64.7	65.3
14	68.7	69.8
16	74.8	73.4
18	80.3	75.5
20	81.6	77.3
22	84.3	78.9
24	85.4	80.5
26	86.9	82.1
28	86.9	83.6
30	88.1	84.9
32	88.4	86.0
34	89.6	86.5
36	89.5	87.2
38	90.7	87.6
40	90.9	87.9
42	91.6	88.1
44	91.4	88.2
46	91.7	88.1
48	91.0	88.0
50	91.3	87.9
52	91.0	87.6
54	91.2	87.2
56	90.5	86.8
58	90.6	86.6
60	90.4	86.1
62	90.6	85.7
64	90.0	85.3
66	90.1	84.8
68	89.6	84.3
70	89.7	83.8
72	89.2	83.3

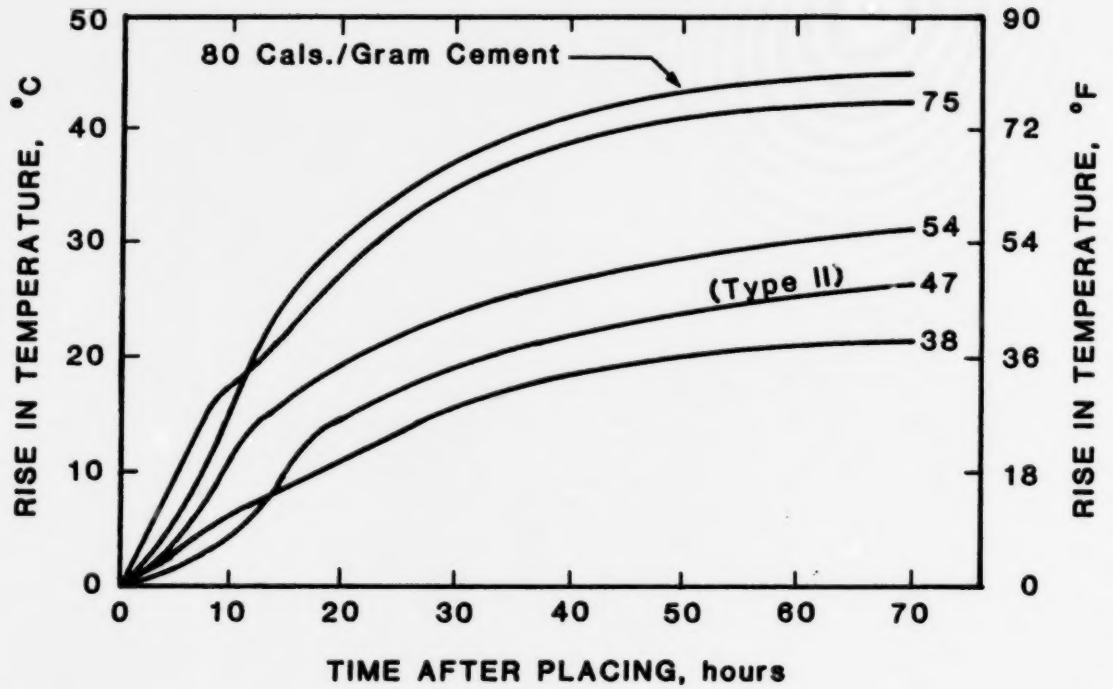

Fig. B1. Temperature Rise in Concrete Made with Different Cements and Cured Adiabatically (4).

(The total heat of hydration of each cement at three days is shown).

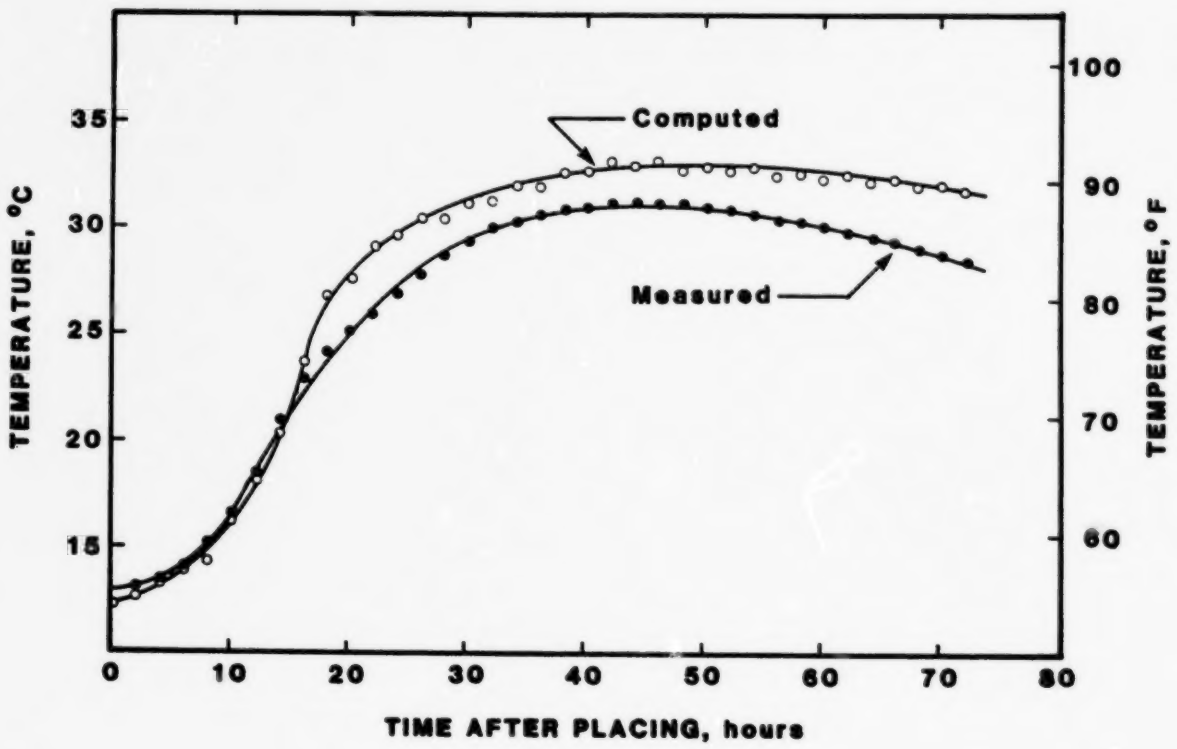

Fig. B2. Computed and measured temperature variation with time at mid-depth of the 1.5 x 1.5 x 1.5-m concrete block.

APPENDIX C

(A) Numerical Computation of Temperature Distribution in the 8.8 x 7.3 x 2.7-m (29 x 24 x 9-ft) Concrete Block Using Schmidt's Method

The selected mixture proportions of concrete for this block are given in Table 6. The ambient temperature and the placing temperature of the concrete are chosen as 24°C (75°F) and 7°C (45°F). The space and time intervals given in Appendix B are used here as follows:

$$\Delta x = 0.5 \text{ ft}; \quad \Delta t = 2 \text{ hrs.}$$

The temperature distribution in one half of the block is calculated because of symmetry. The adiabatic temperature rise in the block is computed from the curve for Type II cement in Fig. B1. For the cement content of 255 lb/cu. yd. and fly ash content of 325 lb/cu. yd. as given in Table 6, the equivalent cement content:

$$C_{eq} = 255 + \frac{325}{4}$$

$$= 336 \text{ lb/cu. yd.}$$

The adiabatic temperature rise for an equivalent cement content of 336 lb/cu. yd. is shown in column 4 of Table C1 and the successive increments of adiabatic temperature at 2 hr. intervals are shown in column 5 of Table C1. The temperature distribution in the block up to 4½ days from placing is computed as shown in Table C2.

(B) The Tensile Strain Caused by Cooling of the 8.8 x 7.3 x 2.7-m Block from the Peak Temperature to the Final Stable Temperature

As given in Appendix B,

$$\Delta t = \frac{100 \times C}{e_t \times R}$$

From Table C2, the peak temperature reached in the block is computed as 92.4°F.

Therefore $\Delta t = 92.4 - 75 = 17.4°F$

Again, the value of R is taken as 50%.

Hence, the thermal strain in the block,

$$C = \frac{\Delta t \times e_t \times R}{100}$$

$$= \frac{17.4 \times 4.0 \times 10^{-6} \times 50}{100}$$

$$= 34.8 \times 10^{-6}$$

which is less than the tensile strain capacity of 62×10^{-6}.

Table C1 - Adiabatic Temperature Rise in the 8.8 x 7.3 x 2.7-m Concrete Block

Time (hrs.)	Adiabatic temperature rise (°C) for cement content of 376 lb/cu yd	Adiabatic temperature rise (°F) for cement content of 376 lb/cu yd	Adiabatic temperature rise (°F) for C_{eq} = 336 lb/cu yd	Δθ (°F)
0	0	0	0	
2	0.5	0.9	0.8	0.8
4	1.3	2.3	2.1	1.3
6	2.0	3.6	3.2	1.1
8	2.5	4.5	4.0	0.8
10	3.8	6.8	6.1	2.1
12	6.0	10.8	9.7	3.6
14	7.5	13.5	12.1	2.4
16	11.5	20.7	18.5	6.4
18	14.0	25.2	22.5	4.0
20	15.0	27.0	24.1	1.6
22	16.0	28.8	25.7	1.6
24	17.0	30.6	27.3	1.6
26	17.5	31.5	28.1	0.8
28	18.0	32.4	29.0	0.9
30	18.5	33.3	29.8	0.8
32	19.3	34.7	31.0	1.2
34	20.0	36.0	32.2	1.2
36	20.5	36.9	33.0	0.8
38	21.3	38.3	34.2	1.2
40	22.0	39.6	35.4	1.2
42	22.5	40.5	36.2	0.8
44	23.0	41.4	37.0	0.8
46	23.3	41.9	37.4	0.4
48	23.5	42.3	37.8	0.4
50	23.8	42.8	38.2	0.4
52	24.3	43.7	39.1	0.9
54	24.5	44.1	39.4	0.3
56	24.8	44.6	39.9	0.5
58	25.0	45.0	40.2	0.3
60	25.5	45.9	41.0	0.8
62	25.8	46.4	41.5	0.5
64	26.0	46.8	41.8	0.3
66	26.3	47.3	42.3	0.5
68	26.5	47.7	42.6	0.3
70	26.8	48.2	43.1	0.5
72	27.0	48.6	43.4	0.3
74	27.3	49.1	43.9	0.5
76	27.4	49.3	44.1	0.2
78	27.5	49.5	44.2	0.1
80	27.7	49.8	44.5	0.3
82	27.8	50.0	44.7	0.2
84	28.0	50.4	45.0	0.3
86	28.1	50.6	45.2	0.2
88	28.2	50.7	45.3	0.1
90	28.3	50.9	45.5	0.2
92	28.35	51.0	45.6	0.1
94	28.4	51.2	45.8	0.2
96	28.5	51.3	45.8	0
98	28.6	51.5	46.0	0.2
100	28.65	51.6	46.1	0.1
102	28.7	51.7	46.2	0.1
104	28.75	51.8	46.3	0.1
106	28.8	51.9	46.4	0.1
108	28.9	52.0	46.5	0.1

Note: An estimate of the temperature rise after 3 days is obtained by projecting the Type II cement curve in Fig. B1 forward

Table C2 - Temperature Distribution in the 8.8 x 7.3 x 2.7-m Concrete Block

Time (hrs.)	Distance from one boundary (ft)									
	0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5
0	75	45	45	45	45	45	45	45	45	45
		0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
2	75	60.8	45.8	45.8	45.8	45.8	45.8	45.8	45.8	45.8
		1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
4	75	61.7	54.6	47.1	47.1	47.1	47.1	47.1	47.1	47.1
		1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
6	75	65.9	55.5	52.0	48.2	48.2	48.2	48.2	48.2	48.2
		0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
8	75	66.1	59.8	52.7	50.9	49.0	49.0	49.0	49.0	49.0
		2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1
10	75	69.5	61.5	57.5	53.0	52.1	51.1	51.1	51.1	51.1
		3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6
12	75	71.9	67.1	60.9	58.4	55.7	55.2	54.7	54.7	54.7
		2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4
14	75	73.5	68.8	65.2	60.7	59.2	57.6	57.4	57.1	57.1
		6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4
16	75	78.3	75.8	71.2	68.6	65.6	64.7	63.8	63.7	63.5
		4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
18	75	79.4	78.8	76.2	72.4	70.7	68.7	68.2	67.7	67.7
		1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
20	75	78.5	79.4	77.2	75.1	72.2	71.1	69.8	69.6	69.3
		1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
22	75	78.8	79.5	78.9	76.3	74.7	72.6	72.0	71.2	71.2
		1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
24	75	78.9	80.5	79.5	78.4	76.1	75.0	73.5	73.2	72.8
		0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
26	75	78.6	80.0	80.3	78.6	77.5	76.4	74.9	74.0	74.0
		1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
28	75	78.6	80.6	80.4	80.0	78.6	77.3	76.3	75.6	75.1
		0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
30	75	78.6	80.3	81.1	80.3	79.5	78.3	77.3	76.5	76.4
		1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
32	75	78.9	81.1	81.5	81.5	80.5	79.6	78.6	78.1	77.7
		1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
34	75	79.3	81.4	82.5	82.2	81.8	80.8	80.1	79.4	79.3
		0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
36	75	79.0	81.7	82.6	83.0	82.3	81.8	80.9	80.5	80.2
		1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
38	75	79.6	82.0	83.6	83.7	83.6	82.8	82.4	81.8	81.7
		1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
40	75	79.7	82.8	84.1	84.8	84.5	84.2	83.5	83.3	83.0
		0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
42	75	79.7	82.7	84.3	85.1	85.3	84.8	84.6	84.1	84.1
		0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
44	75	79.7	82.8	84.7	85.6	85.8	85.8	85.3	85.2	84.9
		0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
46	75	79.3	82.6	84.6	85.7	86.1	86.0	85.9	85.5	85.6
		0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
48	75	79.2	82.4	84.6	85.8	86.3	86.4	86.2	86.2	85.9
		0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
50	75	79.1	82.3	84.5	85.9	86.5	86.7	86.7	86.5	86.6
		0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
52	75	79.6	82.7	85.0	86.4	87.2	87.5	87.5	87.6	87.4
		0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
54	75	79.2	82.6	84.9	86.4	87.3	87.7	87.9	87.8	87.9
		0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
56	75	79.3	82.6	85.0	86.6	87.6	88.1	88.3	88.4	88.3
		0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3

Table C2 - Continued

Time (hrs.)	Distance from one boundary (ft)									
	0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5
58	75	79.1	82.5	84.9	86.6	87.7	88.3	88.5	88.6	88.7
		0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
60	75	79.6	82.8	85.4	87.2	88.3	88.9	89.3	89.4	89.4
		0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
62	75	79.4	83.0	85.5	87.4	88.6	89.3	89.7	89.9	89.9
		0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
64	75	79.3	82.8	85.5	87.4	88.7	89.5	89.9	90.1	90.2
		0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
66	75	79.4	82.9	85.6	87.6	89.0	89.8	90.3	90.6	90.6
		0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
68	75	79.3	82.8	85.6	87.6	89.0	90.0	90.5	90.8	90.9
		0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
70	75	79.4	83.0	85.7	87.8	89.3	90.3	90.9	91.2	91.3
		0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
72	75	79.3	82.9	85.7	87.8	89.4	90.4	91.1	91.4	91.5
		0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
74	75	79.5	83.0	85.9	88.1	89.6	90.8	91.4	91.8	91.8
		0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
76	75	79.2	82.9	85.8	88.0	89.7	90.7	91.5	91.8	92.0
		0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
78	75	79.1	82.6	85.6	87.9	89.5	90.7	91.4	91.9	91.9
		0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
80	75	79.1	82.7	85.6	87.9	89.6	90.8	91.6	92.0	92.2
		0.2	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2
82	75	79.1	82.6	85.5	87.8	89.6	90.8	91.6	92.1	92.2
		0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
84	75	79.1	82.6	85.5	87.9	89.6	90.9	91.8	92.2	92.4
		0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
86	75	79.0	82.5	85.5	87.8	89.6	90.9	91.8	92.3	92.4
		0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
88	75	78.9	82.4	85.3	87.7	89.5	90.8	91.7	92.2	92.4
		0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
90	75	78.9	82.3	85.3	87.6	89.5	90.8	91.7	92.3	92.4
		0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
92	75	78.8	82.2	85.1	87.5	89.3	90.7	91.7	92.2	92.4
		0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
94	75	78.8	82.2	85.1	87.4	89.3	90.7	91.7	92.3	92.4
		0	0	0	0	0	0	0	0	0
96	75	78.6	82.0	84.8	87.2	89.1	90.5	91.5	92.1	92.3
		0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
98	75	78.7	81.9	84.8	87.2	89.1	90.5	91.5	92.1	92.3
		0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
100	75	78.6	81.9	84.7	87.1	89.0	90.4	91.4	92.0	92.2
		0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
102	75	78.6	81.8	84.6	87.0	88.9	90.3	91.3	91.9	92.1
		0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
104	75	78.5	81.7	84.5	86.9	88.8	90.2	91.2	91.8	92.0
		0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
106	75	78.5	81.6	84.4	86.8	88.7	90.1	91.1	91.7	91.9
		0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
108	75	78.4	81.6	84.3	86.7	88.6	90.0	91.0	91.6	91.8